PTO 2003-1116

Japan, Kokai

Document No. 4-343318

TORSIONAL VIBRATOR

[Nejiri Shindoshi]

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UNITED STATES PATENT AND TRADEMARK OFFICE

Washington, D.C. January, 2003

Translated by: Schreiber Translations, Inc.

Country	:	Japan
Document No.	:	4-343318
Document type	:	Kokai
Language	:	Japanese
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Applicant	:	Fuji Electric Co., Ltd.
IPC	:	G 02 B 26/10
Application date	:	May 20, 1991
Publication date	:	November 30, 1992
Foreign Language Title	:	Nejiri Shindoshi
English Title	:	TORSIONAL VIBRATOR

Specification /2[*]

1. Title of the Invention: TORSIONAL VIBRATOR

2. Claims

1. A torsional vibrator, characterized by being equipped with a plate-shaped member having first and second movable electrodes with a comb tooth shape formed by sandwiching an insulating film between them at both ends, a pair of holding members for coupling the plate-shaped member with a fixed substrate, and fixed electrodes having comb teeth meshing with the comb teeth formed in the above-mentioned plate-shaped member.

2. The torsional vibrator of Claim 1, characterized by being constituted by laminating one or more fixed electrodes with the same comb teeth on the above-mentioned fixed electrodes.

3. Detailed explanation of the invention

[0001]

(Industrial application field)

The present invention pertains to a screw vibrator applicable to an optical scanning of optical equipments, etc.

[0002]

(Prior art)

As such a conventional element, for example, there is an

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[*] Numbers in the margin indicate pagination in the foreign text.

optical scanning element (optical deflector) being electromagnetically driven by installing a reflecting mirror and a driving coil in a span band, however since it is necessary assemble each independent part, its miniaturization is difficult. As one of the methods for solving this drawback, it is also known that the span band and the reflecting mirror are formed in a body. Figure 7 shows such a device, and for example, IBM "R&D" Vol. 24, p.631, '80 is reported. In the figure, 21 is a vibrator in which span band 22a and 22b and a reflecting mirror 23 are formed in a body from a silicon plate, and 24 is a substrate made of glass. The reflecting mirror 23 contacts with a projection 25 of the substrate 24 at the center, and at its left and right, a fixed gap is held by a recession 26. 27a and 27b are electrodes installed on the substrate 24, and a voltage is applied between one electrode and the mirror 23 from the outside by an appropriate means, so that the mirror 23 is absorbed and inclined by an electrostatic attraction. Thereby, the light contacted with the mirror 23 is scanned in an arrowhead in Figure 7(ii). In other words, if the mirror 23 is horizontally inclined at ϕ, the light is shaken by 2ϕ.

[0003] In such a device, only the electrodes with a fixed gap may be installed to drive the reflecting mirror, and its miniaturization is also easy. However, in order to increase the torsional angle of the reflecting mirror, it is necessary to increase the gap distance by deepening the recession, however the voltage proportional to square of the gap distance must be

applied. Therefore, it is difficult to make the increase of the torsional angle and a low voltage drive compatible. Accordingly, this applicant proposes a device as shown in Figure 8 (hereinafter, also called a proposed device). Also, (i) in the figure is an oblique view, and (ii) is its cross section. As shown in (i) of the figure, in this device, a torsional vibrator 30 is constituted by forming frame 36 formed of an insulator, fixed electrodes 35 consisting of a silicon substrate 37 joined with the frame, plate-shaped member 31, beam 33 as a holding member, and movable part fixing material 34 in a body by a photoetching process. Furthermore, as shown in (ii) of the figure, the plate-shaped member 31 is pushed up by a support member 38, and a step X is installed while leaving a slight overlap in the movable electrodes 32 and the fixed electrodes 35. On the other hand, a reflecting mirror 31A installed at the plate-shaped member 31 is rotated round the support member 38 by applying a voltage between the fixed electrode 35 and the movable electrode 32 of one side. In this manner, since a driving force is obtained by the stepped electrodes with a comb tooth shape, miniaturization and lightness are realized, and if the step difference is increased, the torsional angle can also be increased. Furthermore, if the comb teeth are increased, a low-voltage drive is possible.

[0004]

(Problems to be solved by the invention)

However, in order to increase the torsional angle by such a

device, it is necessary to thicken the plate-shaped member, so that the moment of inertia round the rotational shaft is increased, thereby lowering the frequency. For this reason, there is a limit in the improvement of the optical scanning speed. Therefore, the purpose of the present invention is to enable a low-voltage and high-speed drive and to obtain a thin type and a large torsional angle, compared with the proposed device.

[0005]

(Means to solve the problems)

In order to achieve such a purpose, the present invention is characterized by being equipped with a plate-shaped member having first and second movable electrodes with a comb tooth shape formed by sandwiching an insulating film between them at both ends, a pair of holding members for coupling the plate-shaped member with a fixed substrate, and fixed electrodes having comb teeth meshing with the comb teeth formed in the above-mentioned plate-shaped member. Also, it is characterized by being constituted by laminating one or more fixed electrodes with the same comb teeth on the above-mentioned fixed electrodes.

[0006]

(Operation)

If a voltage is applied between two movable electrodes and fixed electrodes, an electrostatic force corresponding to a potential difference from the fixed electrodes is exerted in the mutually vertical outward direction to two movable electrode

surfaces, so that the plate-shaped member is rotated by a vertical outward torque being generated in the other electrode around the holding member. Since the electrostatic force being exerted on one electrode has the same size in the opposite fixed electrodes with a comb tooth shape, the torsional angle can be increased with the increase of the thickness of the fixed electrodes. Furthermore, since the electrostatic force is exerted on the comb teeth of the movable electrodes, if the number is increased, a low-voltage drive is possible.

[0007]

(Application examples)

Figure 1 is an oblique view showing an application example of the present invention. Figure 2 is its cross section of A. In this application example, a movable member (plate-shaped member), a pair of holding members 3a and 3b, and a pair of fixed electrodes 5a and 5b (also, the electrode 5b is not shown in the figure) are formed in a body from one sheet of silicon wafer by a photoetching process and joined with a glass substrate 7, and the

fixed electrodes 5a and 5b are separated from the other members /3
by an etching or mechanical means and insulated. Also, in the etching process of the silicon wafer, aluminum (Al) being an insulating film 11 of SiO_2 and a second electrode 12 (see Figure 2) are laminated on the surface of the plate-shaped member 1 by sputtering, and the surface and the back face are masked. Then, etching is carried out so that the external shape of the

torsional vibrator 10 may be left from the surface and the plate thickness may be left from the back face. Since the holding members 3a and 3b are installed on the axis passing through the centroid of the plate-shaped member 1 and there is an appropriate gap D between the movable electrodes 4 and the fixed electrodes 5, the plate-shaped member 1 can be rotated round the holding members 3a and 3b.

[0008] In such a constitution, if a voltage is applied as shown in Figure 2 between the fixed electrode 5a and the first movable electrode 13 and the second movable electrode 12 constituting part of the plate-shaped member 1, electrostatic forces f_1 and f_2 are respectively exerted in the vertical outward direction on the first and second electrodes. If the dielectric constant of the air is ϵ, the electrode length is L, the potential difference between each movable electrode and fixed electrode is V, and the distance between the fixed electrode and the movable electrode is D, the force f is expressed by $f = \epsilon \cdot L \cdot V^2/2D$. Therefore, for example, if the potential of the second movable electrode is set so that it may be the same as that of the fixed electrode, $f_2 \fallingdotseq 0$, and $f = f_1 - f_2 \fallingdotseq f_1 \fallingdotseq \epsilon \cdot L \cdot V^2/2D$. Thus, if the movable electrode is constituted by n pieces of comb teeth, a driving force of 2nf is obtained. Even if a voltage is applied to the other fixed electrode, a similar force is obtained, and the plate-shaped member is rotated at an angle of ϕ round a support. Thus, if a reflecting mirror is installed in the plate-shaped member, an optical scanning of 2ϕ is possible.

[0009] In this manner, since the movable electrodes and the fixed electrodes are formed in a comb tooth shape and the movable electrodes are moved by the distance as much as the thickness of the opposite fixed electrodes, if there is an appropriate rigidity in the plate-shaped member, it may be as thin as possible. Thus, the moment of interia can be decreased, and the resonance frequency can be set to a high value. Also, if the silicon etching depth from the back face is increased, the torsional angle can also be increased, and if the number of comb teeth is increased, a low-voltage drive is possible. Also, the holding members 3a and 3b have been a linear shape in this example, any shape may be adopted as long as there is a torsional rigidity that can support the plate-shaped member. Also, the material constituting the torsional vibrator is not limited to the silicon, and any material may be adopted as long as a similar working is possible. Furthermore, if two electrodes are formed in the plate-shaped member, the torsional vibrator itself may also be an insulator.

[0010] Figure 4 is an oblique view showing another application example of the present invention. Figure 5 is its cross section of B. As shown in Figure 4, 10 is a torsional vibrator consisting of plate-shaped member 1, first fixed electrode 5a, substrate 7, etc., explained by Figure 1, and second fixed electrodes 15a and 15b with the same shape as that of the first fixed electrode are aligned on it and joined. Since the second fixed electrodes 15a and 15b must be electrically connected to

only the respective corresponding first fixed electrodes 5a and 5b, connecting parts 17a-17d are separated by an etching or mechanical means to insulate them from the other electrodes. Then, as shown in Figure 5, a movable electrode 4a is positioned at the central part of the fixed electrode 5a and the second electrode 15a.

[0011] Figure 6 is a cross section in the direction perpendicular to Figure 5. In the above-mentioned constitution, for example, if 0 volt is applied to the first movable electrode 13, V_{cc} volt is applied to the second movable electrode 12, V_{cc} volt is applied to the fixed electrodes 5a and 15a, and 0 volt is applied to the fixed electrodes 5a and 15b, since an electrostatic force proportional to square of the potential difference from the fixed electrodes is generated in the vertical outward direction on each surface of the first and second movable electrodes, an equal torque is generated at the left and right of the movable electrodes as shown by an arrowhead F in the figure, assuming only the electrostatic force of the torque. Thereby, the torsional vibrator is rotated. If the voltage being applied to the fixed electrodes 5a, 15a and 5b, 15b is horizontally opposite, an opposite torque is generated. Thus, if the same voltage as that of the non-junction case is applied by joining the second fixed electrode on the first fixed electrode, a twice torque is obtained, and a large-amplitude drive is possible at low voltage. Also, in this application example, the second fixed electrode has been joined on the first fixed electrode, however

it may be jointed under the first fixed electrode. For example, it may also be joined between the first fixed electrode and the substrate.

[0012] Since the ratio of the digging depth and the width by etching, that is, the aspect ratio cannot be too large but is usually about 2.5, the degree of integration is raised by reducing the width of the comb teeth in order to raise the efficiency of the driving part. In other words, if the number of comb teeth is increased, since the etching depth from the back face of the first fixed electrode is decreased, the thickness cannot be large, and there is a limitation in the amplitude of the torsional vibrator. However, in this application example, since the thickness of the fixed electrodes can be increased by joining the second fixed electrode, the amplitude can be further raised. Also, several sheets with the same shape as that of the second fixed electrode are laminated, so that the amplitude of the vibrator can also be increased several times.

[0013]

(Effects of the invention)

According to the present invention, two electrodes with a comb tooth shape are laminated via an insulating film on a movable member with a thin plate shape, and holding members joined with the movable member and a substrate on the axis passing through the centroid of the movable member and fixed electrodes sufficiently thicker than the movable electrodes being meshed with the above-mentioned comb teeth are formed on the

substrate. The potential difference between the first and second electrodes and the fixed electrodes is set to be large, and driving is carried out by the difference in the electrostatic force being generated in the vertical and outward direction to the first and second electrodes. Thus, even if the movable electrodes are thin, a necessary driving force can be obtained in the opposite fixed electrodes. For this reason, the moment of inertia of the torsional vibrator can be decreased, and the resonance frequency can be set to a high value, so that a high-speed drive is possible. Also, if the distance in the thickness direction of the fixed electrodes is increased, the torsional angle can be increased, and if the number of comb teeth is increased, the driving force can be raised. Thus, a large torsional angle can be easily obtained, even at low voltage. Also, if the second fixed electrode is joined on the first fixed electrode, the movable electrodes are positioned at its center, and a voltage is applied to the left and right fixed electrodes, since a twice torque is generated around the holding members in the torsional vibrator, a large torsional angle can be obtained at low voltage. Since the torque being exerted on the torsional vibrator is a couple of forces, forces other than the rotation are not exerted on the support member, and a stable optical scanning is possible without generating a vertical movement and a surface distortion of the vibrator. Furthermore, the torsional angle can be further increased by laminating several times.

4. <u>Brief description of the figures</u>

Figure 1 is an oblique view showing an application example of the present invention.

Figure 2 is a cross section of A of Figure 1.

Figure 3 is a cross section for explaining the operation of Figure 1.

Figure 4 is an oblique view showing another application example of the present invention.

Figure 5 is a cross section of B of Figure 4.

Figure 6 is a cross section for explaining the operation of Figure 4.

Figure 7 is an illustrative diagram for explaining a conventional galvanomirror.

Figure 8 is an illustrative diagram for explaining the proposed device.

Explanation of numerals:

1 Movable member (plate-shaped member)

4 Movable electrode

7 Glass substrate

3a Holding member

3b Holding member

4a Movable electrode

4b Movable electrode

5a Fixed electrode

5b Fixed electrode

10 Torsional vibrator

11 Insulating film

12 Second movable electrode

13 Support member (first movable electrode)

15a Second fixed electrode

15b Second fixed electrode

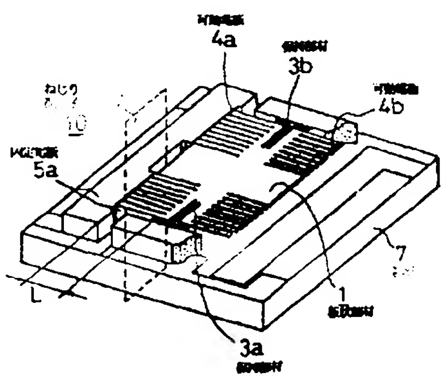
17a Connecting part

17b Connecting part

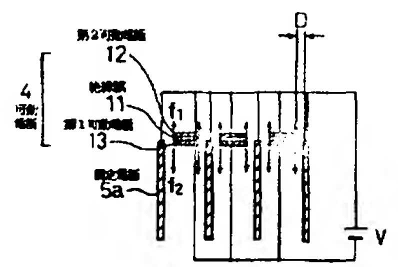
17c Connecting part

17d Connecting part

【図1】



【図2】



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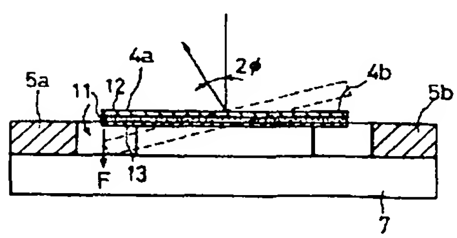

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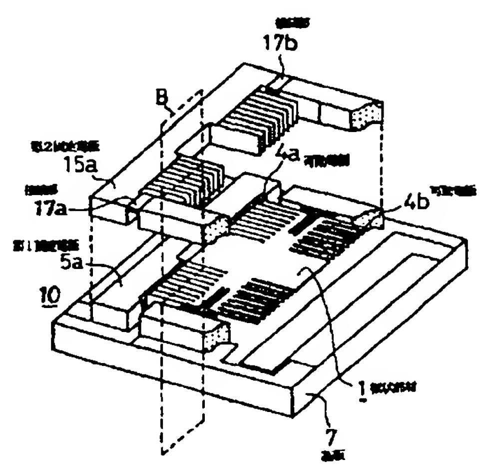


Figure 1:

1	Plate-shaped member
3a	Holding member
3b	Holding member
4a	Movable electrode
4b	Movable electrode
5a	Fixed electrode
10	Torsional vibrator

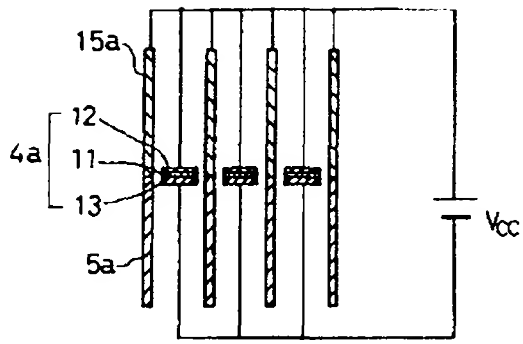
Figure 2:

4	Movable electrode
5b	Fixed electrode
11	Insulating film
12	Second movable electrode
13	First movable electrode

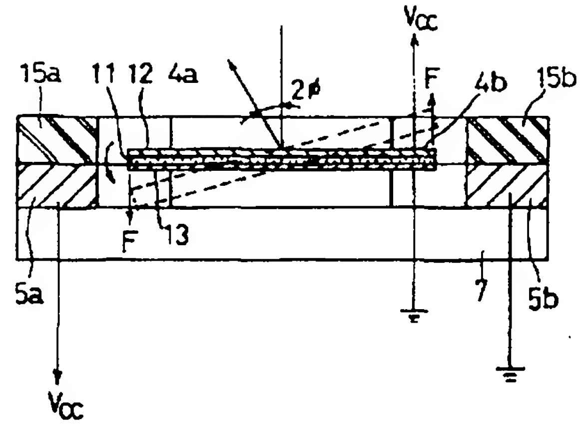
Figure 4:

1	Plate-shaped member
4a	Movable electrode
4b	Movable electrode
5a	First fixed electrode
7	Substrate
15a	Second fixed electrode
17a	Connecting part
17b	Connecting part

【図5】


15a
12
4a
11
13
5a
Vcc

【図6】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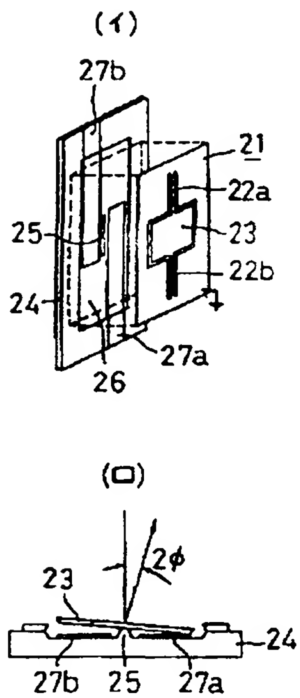
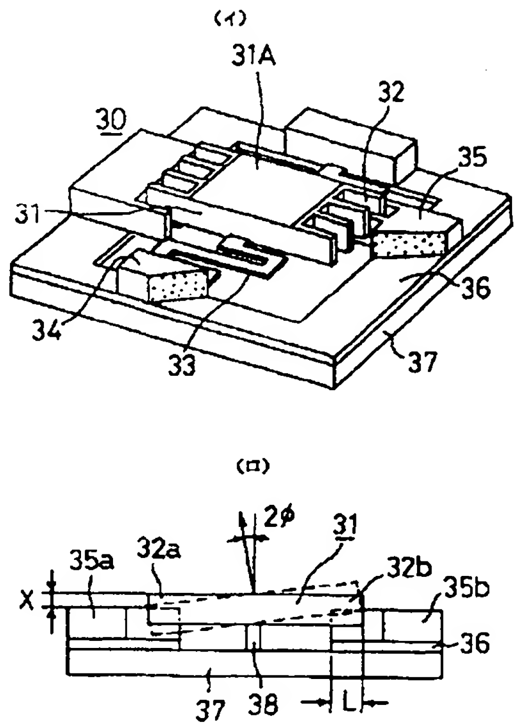
12
4a
2φ
F
4b
15b
F
13
5a
7
5b
Vcc

【図7】


(イ)
27b
21
22a
25
23
22b
24
27a
26
(ロ)
2φ
23
24
27b
25
27a

【図8】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